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THE FOSSIL FLORA OF IOWA COAL BALLS

I. DISCOVERY AND OCCURRENCE

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COAL BALLS are fossiliferous mineral nodules which, because they occur occasionally in coal deposits, are of special interest to both botanists and geologists. Usually these nodular structures are composed of calcite or dolomite, more rarely pyrite, but they are always complex mixtures of inorganic substances. Well-preserved fragments of plants are often found in coal balls and these fossils are the chief source of information concerning the anatomy of Carboniferous plants. The plant morphologist is familiar with a score of extinct plants such as *Lepidodendron* and *Calamites* which have become fundamental to an understanding of our concepts of phylogeny and evolution, yet he is prone to overlook the fact that we owe our knowledge of them largely to petrifactions in coal balls.

A century has passed since Henry Witham of Lartington published his *Internal Structure of Fossil Vegetables found in the Carboniferous and Oolitic Deposits of Great Britain*, which although it included notes on only twelve species, was the first carefully executed histological work on fossil plants. Now the internal morphology of more than two hundred Paleozoic plants has been described, but not more than twenty of these plants are

known with a degree of completeness. During the middle of the nineteenth century Binney, Carruthers, and Williamson began a brilliant period of investigation on British coal balls which culminated in the fruitful researches of Scott, Maslen, Benson, and their students.

Coal balls have been found in England, Holland, Belgium, France, Germany, Moravia, Russia, Australia, and the United States. They have been reported also in China, but so far as I am aware, no plant forms have been described from Chinese specimens.

The first discovery of coal balls in America was announced nearly twenty years ago when the late Doctor A. C. Noé recognized them in Illinois. Subsequently he located coal balls in Indiana and Kentucky, and reported pyritized nodules from Iowa. Plant remains were observed in all of these, but no comprehensive report on their botanical content has ever been published. Noé made several contributions to our knowledge of their plants in enumerations of species, the number of entries increasing rapidly with encouraging variety (1925, 1931, 1931). However, the detailed descriptions he left to his students, notably Hoskins, Graham (1934), Reed, Krick, and Schopf. Recently Arnold and Steidtmann have also made additions to the flora of Illinois coal balls.

Two years ago, Mr. Frederick Oliver Thompson of Des Moines, Iowa, began a diligent search for new occurrences of coal balls and his efforts were rewarded by their discovery at four localities in the Des Moines Series of the Pennsylvanian deposits of Iowa. He has transmitted to the Botanical Museum of Harvard University more than 1800 nodules varying in their diameters from 3 to 22 inches.

A person unfamiliar with the study of structurally preserved fossil plants is frequently unaware of the difficulties which attend the investigation of paleobotanical

remains and of the quantity of material necessary for an adequate description. From the very beginning of a problem the investigator is faced by the fragmentary nature of the plant parts and the painstaking "piecing together" of small fragments. Even though one can scarcely doubt the attachment of a particular seed to a twig or a given leaf to a stem, organic connection, that is actual union of parts, must be observed before attachment is proven. As a result of this necessity for caution, numerous generic and specific names must be applied to parts of a single biological species. If an investigation be made of hundreds of examples of the same kind, the fragments which show attachments, such as small branches on larger portions of the axis, inflorescences borne upon twigs, and the like, may ultimately yield noteworthy results. However, much restraint and caution must be used in these problems.

We have found, accidentally, a method which has revealed a surprising number of cases of organic union of parts: sporangia on fern fronds, spores in sporangia, ovules within inflorescences, fronds attached to petioles, and pollen-grains in staminate strobili. By the same method we have observed impressions of various fossil plants in the coal balls as well as the mineralized portions showing histological detail. Thus the Iowa coal ball flora contains nearly a dozen species known both externally and internally.

Within recent years some progress has been made in this direction upon Mesozoic floras by Harris, Thomas, and Florin, but little upon Paleozoic, though Florin, Walton, Hartung, and the writer have made small beginnings.

Method of Study

Each coal ball was split into smaller fragments with a sledge-hammer. It was found that each coal ball, with

very rare exceptions, broke in a plane parallel to the longest axis and approximately at right angles to the shortest axis. These planes of weakness would seem to be "bedding planes." Although the balls are nodular, they are not concretions—that is, formed by concentric accretions of sediment or crystalline substance. The whole nodule is formed at the same time and formed congenerically with the fossil it encloses.

The ball was then broken into smaller fragments somewhat smaller than a man's fist. By means of a lapidary's saw, small blocks containing selected fossilized plant structures were cut, and later ground upon a revolving lap with carborundum grit. Serial nitrocellulose peels were then made from all desirable materials. More than 3500 plant specimens have been preliminarily identified and from 3 to 40 peels have been prepared from each specimen. To date, more than 38000 microscopic slides have been made.

The first stage in the study of this extensive material has been concerned with a rapid and cursory survey of the flora—cursory in the sense that the histological details of the forms have not been described or observed closely. The microscopic slides represent sixty-two to sixty-six species most of which are new. The species are broadly defined and the number now recognized is much less than the original estimate; for example, there is only one *Mesoxylon*, whereas we had tentatively separated four or five. The task before us is, of course, the description of each species in as great detail as material permits, with "serial sections" of all essential parts.

Plan of the Work

This paper has been written as an introduction to a series of contributions concerning the taxonomy, histology, and morphology of the significant members of the

flora contained in Iowa coal balls. Naturally the study of a flora containing more than sixty species, most of which appear to be either undescribed or very imperfectly known, will require a number of years for investigation. It is hoped, therefore, that the description of each plant species, or group of related species, will be published when its study has been completed. The descriptions and illustrations of three forms in this flora are now awaiting publication: the fructification of a new *Botryopteris*, the embryo of a *Cordaicarpus*, and a new seed of the *Mazocarpon* type.

Plant Content

The Iowa coal ball flora differs from all other described coal ball floras in that it is essentially gymnospermous rather than pteridophytic. In order of abundance the plant groups represented are: *Cordaitales*, *Pteridospermae*, *Filicales*, *Sphenophyllales*, *Calamitales*, and *Lepidodendrales*.

Cordaitales

The form-genus *Cordaites* was originally proposed for strap-shaped linear leaves belonging to large arborescent cone-bearing gymnosperms. There are several thousands of fragments belonging to probably a single biological species or possibly to two species. Most numerous of these are specimens of wood of the *Mesoxylon* type. The wood is found in fragments ranging in size from small twigs to a stump measuring nineteen inches in diameter. There is a large discoid pith (the so-called *Artisia* structure). Next in abundance are the leaves which have not yet been identified. Both the impression and the histological structure of these foliar organs have been observed. Root fragments are frequently found, but their connection is only implied by association. The seeds known as

Cordaicarpus, are very numerous, more than one hundred individual examples have been found. Of this number eight have well preserved dicotyledonous embryos. These are the first known Paleozoic embryos. There are nearly three hundred microsporangiate strobili and, curiously, only six megasporangiate strobili. The polliniferous inflorescences contain winged pollen-grains each with a multicellular gametophyte of approximately twenty to thirty cells. In addition there are specimens of vegetative buds and enrolled leaves. If these detached parts can subsequently be demonstrated to belong to a single species, it will be one of the most completely known Carboniferous plants.

Pteridospermae

The most abundant seed-fern stem type occurring in the Iowa coal balls is a tristelic species of *Medullosa* which is most probably identical with *Medullosa Noei* Steidtmann, which in turn belongs to the *Medullosa anglica* group. Large petioles, as well as many smaller ones, have been prepared for detailed study. Leaves of *Neuropteris Scheuchzeri* Hoffman, *Neuropteris rarinervis* Bunbury, and *Linopteris* cf. *obliqua* are abundantly preserved both as impressions and petrifactions. There are several little known fructifications (one a *Telangium*) which occur in the flora. Eight nominal species of detached seeds of the *Lagenostoma*, *Rhabdocarpus*, and *Trigonocarpus* types occur sparingly, as well as a variety of other undescribed forms. Seeds of the *Lagenostoma* type are rare.

Filicales

By delicate manipulation with needles and chisels we have been able to expose impressions of two species of *Pecopteris* foliage bearing sori; one an *Asterotheca* and

the other a probable *Ptychocarpus*. Detached sporangia are very numerous in all of the coal balls. Petioles are abundant and the following forms are well represented: three (possibly only two) species of *Botryopteris*, at least two species of *Etapteris*, one *Anachoropteris*, one *Ankyropteris*, an actinostelic fern which is apparently new, and several complex *Zygopteridaceae*. Fine specimens of a polystichous *Psaronius* are moderately abundant. One species of *Botryopteris* is known from the fructification as well as the petiole. This remarkable form, represented in the collections by three specimens, has a great globose cluster of sporangia borne terminally upon the frond.

Sphenopsida

Sphenophyllum, stems and strobili (the *Sphenophyllum Dawsoni* type) are found occasionally. The *Calamitales* are represented in the collections by only a few specimens of the *Arthropitys communis* type, a beautiful *Macrostachya*, and two specimens of a small homosporous *Calamostachys*. These two forms of strobili contain well-preserved spores.

Lycopsida

The Lycopsida seem to have been very rare. Only two specimens of a siphonostelic *Lepidodendron* with a mixed pith of the *Lepidodendron selaginoides* type have been found. In addition, however, there are occasional seed-like structures referable to *Mazocarpon* and *Lepidocarpon*, a megasporophyll bearing sixteen large megaspores (cf. *Lepidophyllum missouriense* White), and a single needle-like leaf of *Sigillaria*.

It is apparent then, that the Lycopsida and Sphenopsida play a very minor rôle in this flora. That they are meagerly represented is evidenced both by the fewness of the species, and, more convincingly, by the scarcity of

individuals. That this is not merely an apparent rarity is indicated by the large number of specimens which have been studied.

Discussion

The well-known Middle Coal Measures coal ball flora of England is a *Lyginopteris—Lepidodendron—Calamites* flora with *Mesoxylon*, *Medullosa*, and filicineans being satellitic types. The same association occurs in Holland and Belgium, but in the latter *Lyginopteris* seems to be more rare. We have studied nearly a hundred nodules from Belgium and several score from England and Holland, and our results on this small number agree with those noted in Hirmer's resumé (1928).

Judging from the enumerations of species found in Illinois coal balls, it would appear that the flora is very similar to European coal ball floras except that it includes also geologically younger elements, notably the so-called Stephanian fern types.

The Iowa coal ball association is *Cordaites—Medullosa—Psaronius*, with other ferns being complementary elements.

Nature of the coal balls

Analysis

The histological detail preserved in these Iowa coal balls, although not so excellent as in many types of silicified nodules, is so good that it is necessary to consider the unusual nature of the petrifactions.

The coal balls are highly pyritic, so much so that the specific gravity averages about 3.5 and the luster of a cut surface is metallic. In order to verify the optical identification of the ingredients in the matrix, a sample was submitted to F. A. Gonyer of the Geological Museum of Harvard University. He reports the following analysis:

Sulphur	(S)	32.27
Iron	(Fe)	27.12
Iron Oxide	(Fe_2O_3)	.76
Calcium Oxide	(CaO)	19.56
Carbon Dioxide	(CO_2)	14.87
Water	(H_2O+)	1.47
Water	(H_2O-)	none
Silica	(SiO_2)	.70
Soda	(Na_2O)	.17
Organic Matter		3.10
		100.02

It is noteworthy that no alumina (Al_2O_3) nor magnesia (MgO) has been found in the analysis. This is the more significant because there is usually sufficient dolomite ($CaCO_3 . Mg\ CO_3$) present in a coal ball to warrant the name "dolomitknollen." The pyrite, FeS_2, amounts to nearly 60% of the total, and the Calcite, $CaCO_3$, slightly more than 34%. The organic component is unexpectedly great and stands out in contrast with the 1.8% to 2.5% average reported from typical English coal balls.

Stopes and Watson (1908, p. 193) have given the following analyses of three typical English coal balls:

$CaCO_3$	51.188	87.827	49.355
$MgCO_3$	42.820	6.212	39.682
$FeCO_3$	2.342	1.026	2.247
$MnCO_3$	0.521	0.853	0.597
Al_2O_3	trace	trace	———
$Ca_3P_2O_8$	0.525	trace	0.222
FeS_2	0.339	1.430	3.273
Clay	0.119	0.000	0.053
Organic matter	1.855	2.579	4.064
Free water	0.264	0.100	0.446

It is noteworthy that the "organic matter" in sample three exceeds four percent.

The small crystals of pyrite have not distorted the plant tissues during petrifaction. Study of a ground section of a coal ball reveals that the pyrite is distributed through the matrix in the spaces in and between plant fragments, not in the cells or tissues.

Almost nothing is known concerning the mode of formation of such nodules. The sulphur content, which is in the form of one or more sulphides, is proportionately higher than in the surrounding coal, and it is possible that this indicates that some organic factor associated with the complex process of decomposition is influential in their formation. Small masses of pyrite or marcasite are to be observed in nearly every coal seam, and I suspect that they owe their origin to a kindred, if not identical, process. Stopes and Watson (1908) and Feliciano (1924) agree that coal balls are formed *in situ* and found no evidence in support of the naïve hypothesis that the nodules were transported into a coal-forming environment.

Occurrence

The coal balls reported in this paper have been found in a small area west of the city of Des Moines, Iowa, traversing the boundary between Dallas and Polk Counties. The most abundant material has been collected in the Shuler Mine in Walnut Township, Dallas County, five miles west of Des Moines. The Urbandale Mine, Walnut Township, two miles west of the city limits of Des Moines, has also yielded abundant material.

It is not known whether the coal seams of the Shuler and Urbandale Mines are identical. Coal number 7 of the Shuler Mine is a seam five and one half feet thick, lying 610 feet above sea level and 387 feet beneath the surface of the ground which is at an elevation of 997 feet. The chief seam of the Urbandale Mine, that which contains nodules, varies from four and one half to five and one half

feet in thickness, lies 624 feet above sea level and 185 feet beneath the surface of the ground which has an elevation of 809 feet.

These coal seams belong to the rocks classed in the Des Moines Series of the Upper Pennsylvanian period, which is an age equivalent to the Westphalian C, perhaps to the higher (younger) Westphalian D of western Europe (Darrah 1937). It is hoped that a study of the plants in this flora will contribute data towards the more precise stratigraphy and correlation of the deposits.

There is one additional feature involved in the occurrence of the Iowa coal balls which deserves notice. All of the nodules which I have observed in place in the Shuler Mine were scattered through the upper third of the coal seam, and Mr. Markum called my attention to the fact that this is their usual position throughout those portions of the workings where coal balls have been encountered. The roof of the coal is a black shale which contains marine invertebrate fossils. Several years ago my wife and I collected many coal balls in the Werister Colliery in Liége, Belgium and we observed there that the nodules were scattered through the coal which is overlain by a marine band. Many of the Belgian and English coal balls contain fossil cephalopods. This fact has given rise to the opinion that such nodule formation is "mal de mer" of the coal bed. Coal balls are so unexpectedly irregular in their occurrence that the intimate association of marine sedimentation with coal accumulation usually observed in coal ball bearing seams is more than coincidence.

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Shuler and Mr. John Shuler. We are indebted to these friends who together have sent to the Botanical Museum literally tons of coal balls. We wish to acknowledge also the assistance and genuine interest of Mr. Charles Bendixon, Mr. Frank Markum, and Mr. Joe Johnson. Doctor Charles Keyes and Doctor A. K. Miller have kindly furnished data on the stratigraphy of the deposits.

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